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High-Level Glacial Outwash in the Driftless Area of Northwestern Illinois

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ABSTRACT

New highway cuts about 4 miles southeast of East Dubuque, Jo Daviess County, Illinois, expose outwash gravel not previously observed on the upland surface. The gravel and underlying clayey sandy silt rest on unevenly eroded Galena Dolomite at an elevation of 780 to 800 feet, about 200 feet above the Mississippi River floodplain. Although the pebbles and cobbles are dominantly Galena Dolomite, sand from the matrix contains a distinctive glacial heavy mineral suite. Upland glacial outwash east of the Mississippi River indicates that the river was not in its present position until after Nebraskan glaciation. The valley of the Mississippi and the mature topography of the Driftless Area had largely developed by Kansan time. The course of the river through the prominent Silurian Escarpment south of Galena is explained as an ice marginal feature. The anomalous deep bedrock incision of the major valley, shown by deep borings at Dubuque, may be the result of isostatic depression and marginal elevation (forebulge) caused by the weight of the glaciers.

INTRODUCTION

Exposures of Nebraskan outwash gravel near the east bluff of the Mississippi Valley in the Driftless Area of Jo Daviess County, Illinois, reveal new information about the glacial and erosional history of the area (fig. 1). The gravel, unlike any deposit previously observed in the Driftless Area, locally overlies well bedded clayey sandy silt, possibly lacustrine, which is in contact with the bedrock. The gravel generally is overlain by a sequence of silts, loesses, and buried soils. The presence of the gravel on the upland surface east of the Mississippi

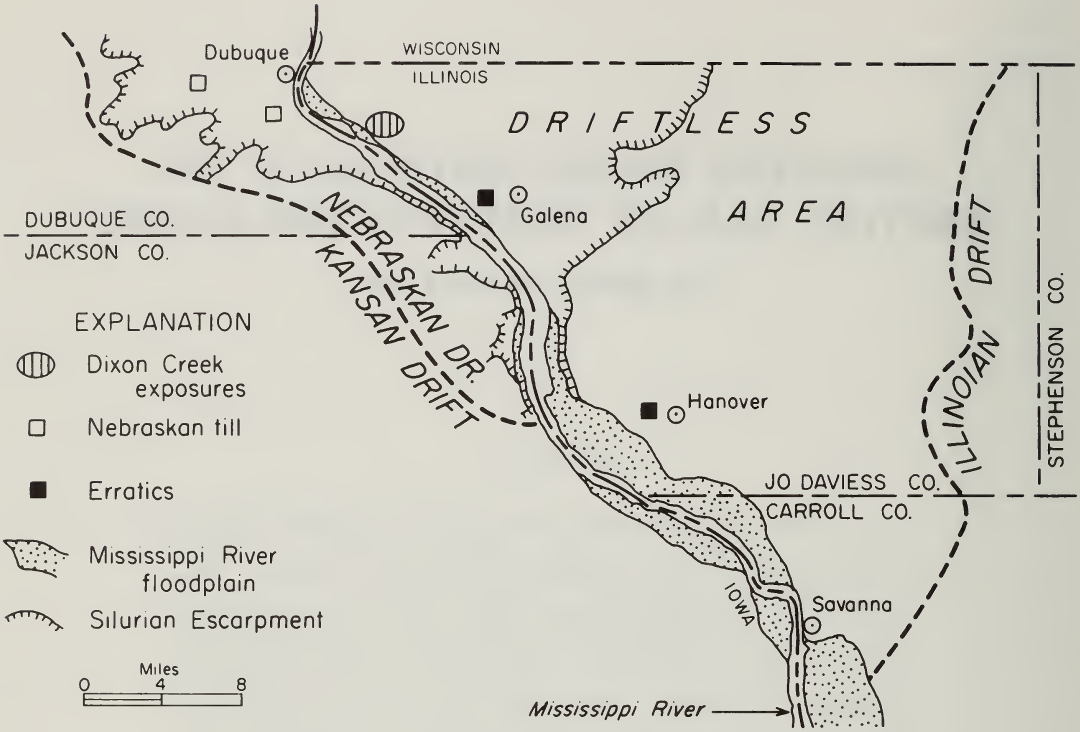


Figure 1 - The Driftless Area in Illinois and the localities described in this report.

River supports the interpretation that the deep dissection of the valley occurred after Nebraskan glaciation and before the maximum of the Kansan glaciation. The mature topography of the Driftless Area, therefore, developed during the early Pleistocene and is not representative of the late Tertiary surface.

Previously unpublished clay mineral analyses by H. D. Glass and heavy mineral analyses by Alan M. Jacobs, both of the Illinois State Geological Survey, are reported.

PREVIOUS STUDIES

Identification of Drifts

The absence of glacial drift in a large area in southwestern Wisconsin and bordering parts of Illinois, Iowa, and Minnesota was noted by Owen (1844) during the earliest geological survey of the Upper Mississippi Valley. Whitney (1862, 1866) outlined the Driftless Area and Shaw (1873) described the boundary of the area in Illinois. Chamberlin and Salisbury (1885) mapped and described the geology of the Driftless Area in detail.

The area of northeastern Iowa extending from the Kansan front eastward to the Mississippi River was considered driftless by Whitney. Chamberlin and Salis-

bury, however, noted the presence of drift in the area but described the part nearest the Kansan front as the "attenuated till and boulder border" and the more distant part as the "attenuated pebble border." They interpreted the attenuated drift as ice-rafted deposits in an extensive lake bordering the Kansan ice sheet. They noted the presence of a few pebbles in the vicinity of Galena above the levels of the later glacial outwash. Although stating that the pebbles might have been transported by human means, they considered them part of the attenuated pebble drift and extended the boundary of the drift across the Mississippi River to Galena. It appears that they did not see the gravel deposits in Illinois described in this report.

McGee (1891) differentiated the drift of northeastern Iowa, then called Kansan, into upper and lower drifts, including tills, separated by widespread water-laid deposits, in places associated with a forest bed. The lower drift was strongly deformed in many places. McGee projected the lower till eastward a few miles beyond the border of the upper drift but drew the drift boundary 5 to 10 miles from the Mississippi River in the part of the area bordering Illinois.

In the Driftless Area, McGee (1891, p. 513) described a local boulder deposit beneath loess exposed in a roadcut immediately west of Linwood Cemetery in Dubuque as consisting of "rounded masses of Galena limestone from 8 or 10 inches in diameter downward to fine powder, piled together without arrangement; including also two or three small rounded erratics. Total exposure, 10 feet. The loess is separated from the subjacent bed by a ferruginous band with stains running down to the uppermost boulders." The gravel is at an elevation of about 750 feet and may be similar to the gravel described in this report. McGee observed similar deposits elsewhere in the Driftless Area and stated that they graded westward to unmistakable glacial drift with abundant erratics.

Trowbridge and Shaw (1916) recorded the presence of cobbles and boulders of igneous and metamorphic rocks, as large as $2\frac{1}{2}$ feet in diameter, in a small valley in Illinois, $1\frac{1}{2}$ miles west of Hanover, nearly 1 mile east of the Mississippi bluffs. The erratics were mostly deeply weathered and were embedded in residual clay from the Maquoketa Shale and Silurian age dolomites.

Williams (1914, 1923) described and mapped many exposures of drift, including till, in the area mapped as driftless by Whitney and McGee. He described several deposits of till in or near the Mississippi bluffs in Dubuque, and referred these deposits to Nebraskan glaciation. Trowbridge (1921) and Kay and Apfel (1929) accepted this identification.

The presence of local accumulations of quartzite cobbles and boulders in the area between Galena and the Mississippi River bluffs was noted during studies by Willman in the lead-zinc district in the 1940's. A few cobbles of greenstone were observed but are rare, and no granite was found. The cobbles and boulders are at levels 100 feet or more above Wisconsinan terraces but clearly are not in place. The localities, all along stream beds in T. 28 N., R. 1 W., are in the NW$\frac{1}{4}$ NE$\frac{1}{4}$ NW$\frac{1}{4}$ Sec. 16, the NE$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 22, the center of the E$\frac{1}{2}$ SW$\frac{1}{4}$ Sec. 23, and the NE$\frac{1}{4}$ NE$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 26.

On both the Glacial Map of North America (Kay, 1945) and the Glacial Map of the United States East of the Rocky Mountains (Hershey and Ruhe, 1959), the drift border was mapped at the Mississippi River, and the marginal drift was mapped as Nebraskan.

In 1964, Frye and Willman, as reported by Trowbridge (1966), described new roadcut exposures containing calcareous till at Rockdale (SW$\frac{1}{4}$ NW$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 1,

T. 88 N., R. 2 E.), only $1\frac{1}{2}$ miles from the Mississippi River bluffs, and near Julien (fig. 2E), west of Dubuque and 5 miles from the bluffs. These exposures are described in this report (Julien Section).

Wright and Ruhe (1965), however, did not accept the deposits outside the Kansan boundary as glacial, and they mapped the area as driftless, with the boundary being essentially that established by Whitney and McGee.

Trowbridge (1966) reviewed the evidence for northeastern Iowa and cited numerous localities where drift, including till, had been observed by himself and others of the Iowa Geological Survey in the area between the Kansan drift and the Mississippi River. He interpreted this as Nebraskan drift and concluded that there is no driftless area in Iowa.

History of Valley Development

The degree of dissection and depth of entrenchment of the master streams in the Mississippi Valley at the beginning of the Pleistocene glaciation has been a controversial problem for many years.

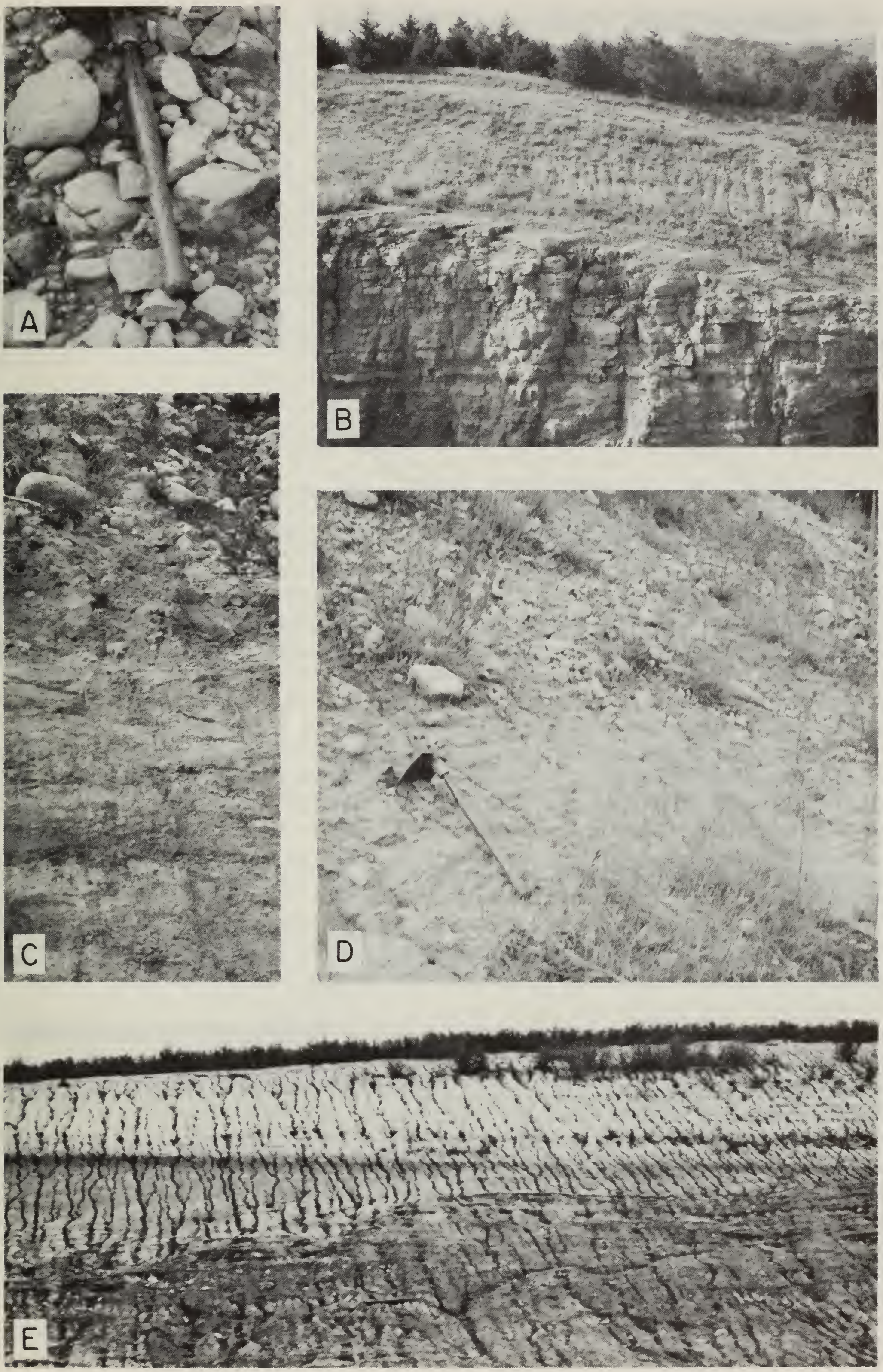
The earliest and most widely accepted interpretation is that the major valleys are preglacial and were deeply entrenched, nearly, if not entirely, to their greatest depth before the earliest glaciation. Chamberlin and Salisbury (1885) and McGee (1891) believed that time was not adequate for the deep valleys to be formed after the first invasion of the ice. Consequently, the deep dissection and mature topography of the Driftless Area has been frequently cited as typical of the preglaciation surface.

Many others also have considered the deepest stage of valley erosion to be preglacial. These include Leverett (1899, 1921, 1942), Trowbridge and Shaw (1916), Carman (1910), Alden (1918), Leighton (1923), and Horberg (1945, 1946, 1950, 1956). With relatively few exceptions, both present and buried valleys were considered to be preglacial (Horberg, 1950, pl. 2).

An alternative interpretation, with several variations, advocated by Hershey (1896a, 1896b, 1897), Williams (1914, 1923), Trowbridge (1921, 1935, 1954, 1959, 1966), Frye (1938, 1963), Trowbridge et al. (1941), Beveridge (1947), and Frye, Willman, and Black (1965) is that the major rivers of the Upper Mississippi Valley were only slightly entrenched in the preglacial surface, that the rivers were shifted to new positions largely along the margins of the glaciers at their maximum extent, and that the deep stages of all valleys, both present and buried, were not preglacial but were eroded during the early Pleistocene.

Figure 2 - Dixon Creek North and Julien Sections.

A. Dolomite cobbles and pebbles in glacial outwash, Dixon Creek North Section.
B. Dixon Creek North Section above Galena Dolomite, 1968.
C. Contact of coarse-grained dolomite gravel on clayey sandy silt, Dixon Creek North Section.
D. Coarse-grained dolomite gravel on clayey sandy silt, Dixon Creek North Section.
E. Julien Section as it was exposed in July 1959. Note truncated soil at top of the till and below the lighter colored loess and the unconformity between the two till units.


A
B
C
D
E

Trowbridge (1935, p. 76) stated, "It is now believed that the Nebraskan glacier advanced southeastwardly over this surface across the old course of the Mississippi River and forced the river to take its present course, which marks the eastward edge of the Nebraskan drift and ice advance. Soon after this course was established, the whole area was uplifted relative to sea level, and the river and its new and old tributaries began to develop their present valleys."

Beveridge (1947) and Trowbridge (1959) recognized both Nebraskan and Kansan drift in a broad and deep buried valley (Poweshick Channel) that trends northwest-southeast through central Iowa to the present Mississippi Valley south of Muscatine. The entrenchment of the valley, therefore, was preglacial. Trowbridge, however, maintained (1959, 1966) that the Nebraskan drift of northeastern Iowa, outside the Kansan drift, was found only on the upland surfaces, whereas the Kansan drift occurs not only on the upland surfaces but in the bottom of the valleys.

DESCRIPTIONS OF DEPOSITS

Recent major cuts along U. S. Highway 20, about 4 miles southeast of East Dubuque, Jo Daviess County, Illinois, expose a coarse-grained gravel on the upland surface not previously observed in this region (fig. 2). The exposures are less than 1 mile from the bluff of the Mississippi Valley. The gravels occur in four principal exposures in an east-west distance of less than 1 mile between Little Menominee River and Dixon Creek (Whisky Hollow). They rest on the unevenly eroded surface of Galena Dolomite at an elevation of 780 to 800 feet, which is about 200 feet above the Mississippi River floodplain to the west and about 50 feet below the highest elements of the adjacent loess-mantled upland. This is within a highly dissected part of the Driftless Area of northwestern Illinois.

The sequence of deposits is shown in the accompanying geologic sections and diagrams (figs. 3 and 4). The basal unit consists of well bedded clayey sandy silt, highly dolomitic, somewhat weathered at the top, as much as 9 feet thick. The silt is overlain by coarse-grained gravel that has a maximum thickness of 30 feet and consists largely of dolomite cobbles with a few small boulders up to 1 foot in diameter in a matrix of sand, small pebbles of chert, and quartz with some clay and silt.

A zone of red residual clay, containing small pebbles of chert and quartz, occurs at the top of the coarse-grained gravels. This red clay is overlain by a thin, leached, red-brown sandy silt (Loveland) with strongly developed soil, reddish tan silt (Roxana), and yellow-tan loess (Peoria). Immediately west of the major gravel exposures near the valley bluff, the Roxana Silt is replaced by leached tan-brown eolian sand attaining a maximum thickness of 20 feet; the Peoria Loess is replaced by calcareous yellow-tan eolian sand, containing fossil snail shells, with a maximum thickness of 60 feet where it extends down into the valley.

The basal silt rests in shallow swales, or erosional channels, cut into the Galena Dolomite (figs. 3 and 4). The contact is on fresh dolomite and the joints under the silt are filled with sandy silty clay of the same type, in contrast to the red residual clay that fills the joints and solution openings in the dolomite generally throughout the region. The basal silt was observed only in the Dixon Creek North and South Sections, and, in both, the bedding dips toward the east. The deposit is poorly sorted, with sand floating in the silt and clay matrix. It is gray and

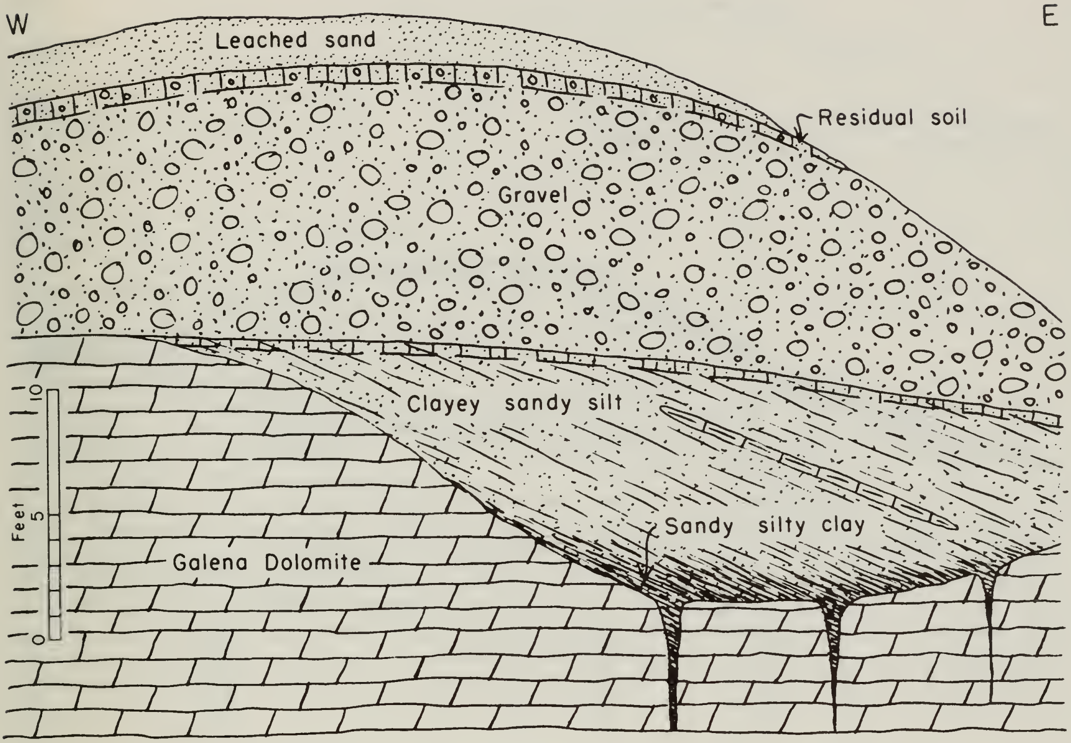


Figure 3 - Generalized diagram of Dixon Creek North Section, SW$\frac{1}{4}$ SE$\frac{1}{4}$ SW$\frac{1}{4}$ Sec. 35, T. 29 N., R. 2 W., Jo Daviess County, Illinois, north side of westbound lane, U. S. Highway 20. Details are given in described geologic section.

mottled and streaked with yellow-tan. Dolomite grains are abundant. The lower part is more clayey, and a secondary calcite-cemented lens occurs parallel to the bedding near the middle of the deposit. The even bedding suggests a lacustrine deposit. The deposit has a sharp contact with the overlying gravel and appears to have been truncated. The eroded top is coincident with the bedrock high that marks the top of a shallow channel (figs. 2, 3, and 4). The top of the deposit is red-brown and is partly leached.

The gravels are coarse-grained with abundant cobbles and a few small boulders. All of the cobbles and boulders, and a high percentage of the pebbles, consist of Galena Dolomite like the bedrock beneath the deposits. Chert, ranging from dark brown to white, becomes progressively more abundant with decreasing size within the pebble fraction. A few pebbles of quartzite were found, as were a few dark-colored fine-grained metamorphic rocks, but no coarse-grained igneous rocks were found in the deposit. The matrix is dominantly quartz sand, but the coarse-grained sand contains abundant chert. The gravel deposit is uniform throughout and lacks bedding. The dolomite cobbles and boulders range from subangular to well rounded and have deeply pitted and etched surfaces; although unoxidized

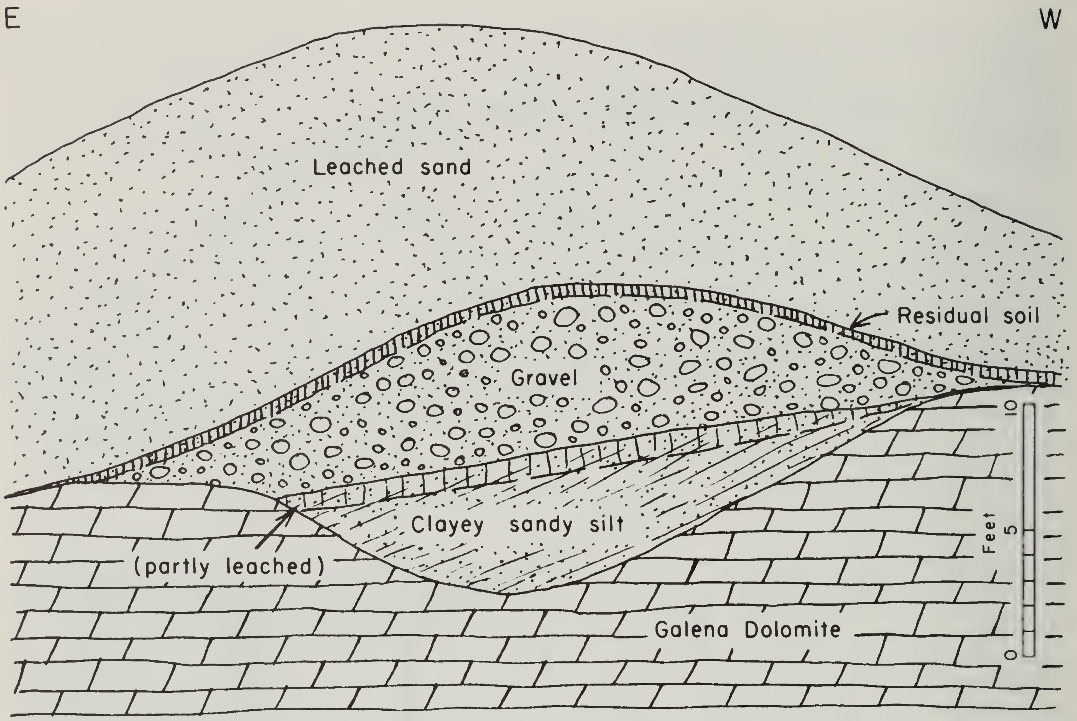


Figure 4 - Generalized diagram of Dixon Creek South Section, south side of west-bound lane, U. S. Highway 20, NW$\frac{1}{4}$ NE$\frac{1}{4}$ NE$\frac{1}{4}$ Sec. 2, T. 28 N., R. 2 W., Jo Daviess County, Illinois. Details are given in described geologic section.

and lacking limonite accumulations, manganese dendrites occur on the surface of many pebbles and cobbles.

X-ray diffraction analyses were made on the less than 2-micron fraction of seven samples and are shown in table 1. The high percentage of expandable clay minerals (montmorillonite) compares favorably with the amounts in the glacial till near Dubuque, Iowa, and indicates a western source (Willman, Glass, and Frye, 1963). The relatively high illite and low kaolinite may be related to a Maquoketa Shale source.

Heavy mineral counts were made on three samples and are shown in table 2. The heavy mineral suite is dominated by garnet, epidote, and hornblende, and zircon and staurolite are common. This suite requires a glacial source, but its content of garnet and zircon is higher, and of hornblende lower, than the suite from the glacial till in Dubuque County, Iowa.

Developed in the top of the gravels and extending with continuity onto the surface of the dolomite beyond the limit of the gravel (figs. 3, 4, and 5) is a residual soil of red clay. The residual soil is commonly 1$\frac{1}{2}$ feet thick, and its relation to the truncated surface of the gravel deposit and bedrock indicates that its

TABLE 1 - CLAY MINERAL ANALYSES

Stratigraphic unit, sample number, and location	Source*	Expandable clay minerals	Illite	Kaolinite plus chlorite
Baylis Fm. (Cretaceous), Adams and Pike Counties, Illinois	A			
Average of 27 analyses		51	17	32
Range of analyses		83 - 10	40 - 7	49 - 8
Dakota Fm. (Cretaceous), Guthrie County, Iowa	A			
Average of 9 analyses		28	32	40
Range of 9 analyses		80 - 0	58 - 11	64 - 9
Nebraskan till, Dubuque County, Iowa	B			
Average of 5 analyses		62	14	24
Range of 5 analyses		64 - 54	17 - 12	33 - 19
Jo Daviess County, Illinois	C			
Nebraskan outwash				
P - 6284		75	17	8
P - 6285		77	16	7
P - 6287		76	16	8
P - 6288		64	30	6
P - 6309		60	30	10
Residuum on outwash				
P - 6280		71	21	8
P - 6289		75	17	8
Residuum on Galena Dolomite				
P - 6300		72	12	16
Residue of Galena Dolomite insoluble in acetic acid				
P - 6299		0	100	0
P - 6313		0	100	0

*A, Frye, Willman, and Glass, 1964; B, Willman, Glass, and Frye, 1963; C, this report, analyses by H. D. Glass, Illinois State Geological Survey.

development followed a period of erosion of the gravels. As the soil on the gravel is overlain by Loveland Silt (Illinoian) containing a Sangamon Soil, and by Roxana Silt and Peoria Loess (Wisconsinan), it is called the Yarmouth Soil. The Yarmouth Soil on the gravel contains rounded pebbles of chert of several types, a few gray quartzite pebbles, and abundant quartz sand, in contrast to the absence of rounded chert pebbles and sand in similar residual clay soils on the dolomite. However, X-ray diffraction analyses indicate that the clay minerals of the residual soil on the dolomite and on the gravel are indistinquishable (table 1). Insoluble residues of both fresh dolomite (P-6299) and a dolomite cobble (P-6313) show a clay mineral content entirely of illite (table 1), and, therefore, the residual clays are largely alteration products of illite.

TABLE 2 - HEAVY MINERAL ANALYSES

Stratigraphic unit or sample number	Location	Source of data*	Percent opaque heavy minerals	Transparent heavy minerals								
				Tourmaline	Zircon	Garnet	Epidote	Rutile	Kyanite	Staurolite	Hornblende	Others
Windrow gravels (average of 4 analyses)	Southwestern Wisconsin	A	72	19	51	tr.†	—	11	3	16	—	tr.
Dakota Formation (average of 3 analyses)	Western Iowa	A	69	32	32	—	—	6	2	28	—	—
Baylis Formation (average of 10 analyses)	Western Illinois	B	76	31	45	1	1	3	3	14	1	1
Kansan till (average of 6 analyses)	Western Illinois	B	42	4	6	11	19	tr.	—	3	53	4
P-502 (till)	Dubuque Co., Iowa	C	29	1	—	11	21	—	—	3	62	2
P-506 (till)	Dubuque Co., Iowa	C	35	—	1	10	20	—	2	2	62	3
P-508 (till)	Dubuque Co., Iowa	C	34	3	3	9	14	1	2	2	62	4
P-6308 (outwash)	Jo Daviess Co., Ill.	D	70	2	12	29	25	2	—	1	12	17
P-6311 (outwash)	Jo Daviess Co., Ill.	D	40	1	2	47	10	2	1	8	23	12
P-6312 (outwash)	Jo Daviess Co., Ill.	D	40	—	5	38	15	—	—	6	21	15

*A, Andrews (1958); B, Frye, Willman, and Glass (1964); C, Willman, Glass, and Frye (1963); D, this report; heavy mineral counts by A. M. Jacobs, Illinois State Geological Survey.

†tr.=trace.

Effects of weathering throughout the gravel deposit are shown by the deeply pitted and etched surfaces of the dolomite pebbles and cobbles, in striking contrast to most gravel deposits where dolomite pebbles below the zone of leached matrix do not have pitted and etched surfaces. Even though the total deposit is largely dolomite, the low percentage of hornblende among the heavy minerals suggests that a significant amount of this mineral was removed by weathering after deposi-

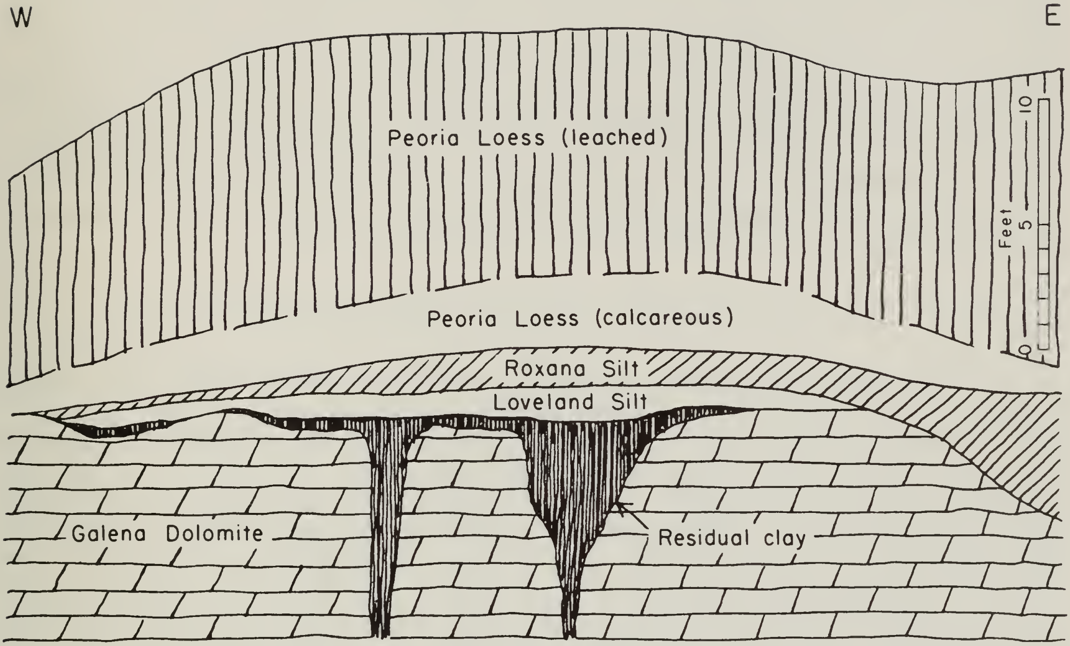


Figure 5 - Generalized diagram of Little Menominee East Section, north side of west-bound lane, U. S. Highway 20, SE$\frac{1}{4}$ SW$\frac{1}{4}$ SE$\frac{1}{4}$ Sec. 31, T. 29 N., R. 1 W., Jo Daviess County, Illinois. Details are given in described geologic section.

tion of the gravel. However, an alternative is that the first advance of the continental glacier over the Tertiary erosion surface to the northwest incorporated the materials of deeply weathered soil, in which the more resistant minerals predominated, and mixed them with freshly eroded crystalline rocks, thus producing a somewhat atypical heavy mineral suite.

INTERPRETATIONS

These high level gravel deposits are interpreted as glacial outwash, deposited near the margin of a continental glacier. The heavy mineral suite (table 2) is typical of glacial deposits and quite unlike any heavy mineral suite known from the Paleozoic, Cretaceous, and Tertiary rocks of the region; the high percentage of weatherable heavy minerals precludes the possibility of derivation from these older rocks. The coarseness of the gravel, its derivation predominantly from one bedrock unit, and its poor sorting are all consistent with deposition at or near the margin of a glacier.

It might be contended that the deposit is alluvium of the Ancient Mississippi River, but the complete absence of cobbles and boulders of rocks from upper Mississippi Valley formations other than the Galena, as well as its topographic position, makes it seem unlikely that this deposit can be related to a through-flowing river.

The highly dolomitic sandy clayey silt that underlies the gravel at two localities has a physical resemblence to some zones in the Cretaceous Baylis Formation of western Illinois and the Cretaceous Dakota Formation of western Iowa. It has a similar clay mineral composition (table 1) and contains muscovite, which is not common in most glacial sands. However, none of the Cretaceous clays and silts that resemble the deposits underlying the gravel are calcareous, and a deposit resembling the overlying coarse-grained gravel of carbonate rocks is unknown in the Cretaceous of the continental interior. Also, the heavy mineral suite is in strong contrast to that obtained from Cretaceous deposits of the continental interior (table 2).

Drift West of the Driftless Area of Illinois

Exposures and analyses of samples from near Julien and Rockdale, Dubuque County, Iowa (fig. 2E; tables 1 and 2; Julien geologic section), support the interpretation that the uplands west of the Mississippi Valley were glaciated to approximately the position of the west valley bluff (Trowbridge, 1966). The possibility that the deposits at Julien represent two episodes of glaciation is suggested by the distinct unconformity within the till deposit and contrasting lithology of the two bodies of till. However, no soil profile was observed on the lower till, and both units may be of Nebraskan age, even though weakly calcareous till rests on noncalcareous till.

The glacial deposits immediately west of the Mississippi Valley are considered Nebraskan in age for the following reasons: (a) the till here occurs beyond the well established boundary of the Kansan drift; (b) the till outside of the Kansan drift boundary is limited to small patches on the uplands and is much more intensely eroded than the Kansan drift; (c) the more continuous Kansan till, in contrast, was deposited after deep erosional dissection of the area; and (d) two tills are present within the adjacent area of Kansan drift, as shown by forest beds between the tills and deformation of the lower drift (McGee, 1891).

Position of the Mississippi Valley

The evidence indicates that the position of the Mississippi Valley in this area is the result of Pleistocene continental glaciation. This position, closely following the margin of the glacial deposits, is consistent with the southeastward advance of the glacier onto the westward-sloping Wisconsin Highlands. The Mississippi Valley transects topographic highs and bedrock structures. About 5 miles south of Galena, the valley cuts through the prominent Silurian Escarpment that stands 300 feet above the adjacent upland level on Galena Dolomite that has been called the Lancaster Peneplain.

The only alternative explanation for the position of the valley is the placement of the stream by superposition from overlying, now removed, flat-lying strata (possibly Cretaceous). If the river had persisted in this position since Cretaceous time, the erosion of the Silurian Dolomite and Maquoketa Shale to form the Lancaster erosion surface on the Galena Dolomite was accomplished while the valley through the escarpment was widened only to about 2 miles. Because of the presence of the Maquoketa Shale underlying the Silurian Dolomite, the high level valley on the Galena Dolomite should have been much wider than the channel formed by later entrenchment of the river in the Galena Dolomite. However, the present valley walls

are steep, and the bench formed by the Maquoketa Shale is narrow, to nearly absent, in places. Therefore, it appears that prior to glacial diversion, the escarpment was continuous, and the area north of the escarpment was drained by a northward flowing stream. Most likely, a pro-glacial lake developed north of the escarpment and drained southward through a col in the position of the present Mississippi Valley. The basal well bedded silts in the Dixon Creek sections may have been deposited in such a lake.

Time of Mississippi Valley Entrenchment

As the position of the river was determined by the Nebraskan glacier, the development of the valley is post-Nebraskan. Because Kansan deposits occur in tributary valleys in Dubuque County, below the surface on which the Nebraskan deposits occur (Trowbridge, 1966), the Mississippi Valley must have had significant erosional development between the times of Nebraskan and Kansan maximum glacial advance. Although objections have been raised to this age assignment for the reason that the time was too short to accomplish this amount of erosion, the placement of the river across the Silurian Escarpment produced ponding north of the escarpment, an extremely increased gradient to the south, and greatly accelerated downcutting.

The outwash gravels described in this report indicate that the Mississippi River was not in its present position when the gravels were deposited. Because the gravels are Nebraskan glacial outwash deposited before topographic dissection, the river was not established before Nebraskan glaciation. The only alternative would be for the glacier to have filled the river valley so that outwash could spill onto the uplands east of the valley. This is improbable because (a) no till has been found in the valley or on the valley slopes, (b) the upland near these deposits and close to the deep valley could not have been dissected before their deposition, and (c) a temporary diversion channel for the Mississippi River should have been formed, and there is none.

Evidence that the Mississippi River was deeply entrenched before the Kansan maximum is supported by the presence of Kansan outwash, generally overlain by Kansan till, in the deepest parts of the major buried valleys throughout central Illinois, as summarized by Horberg (1950). In north-central Illinois, the Ticona Buried Valley (Willman, 1940; Horberg, 1950) is a deep diversion channel that crosses a bedrock high along the LaSalle Anticline and probably results from advance of Kansan ice from the east. It could not have been entrenched before the Ancient Mississippi River was deeply entrenched.

It is possible that in the Driftless Area the Mississippi Valley was not eroded to its maximum depth (below 300 feet elevation) until after Kansan glaciation. This is suggested by the glacial deposits on the Bridgeport Terrace, near Prairie du Chien, Wisconsin, and by the relations of Couler Valley, north of Dubuque, Iowa, as described by Trowbridge (1935, 1954, 1959).

Explanation of Deep Entrenchment

The deep dissection of the Mississippi Valley during post-Nebraskan time requires a gradient far exceeding that of the present bedrock valley floor. It has been suggested (Trowbridge, 1959) that in preglacial time an ancestral Mississippi Valley was deeply eroded through central Iowa and followed the present Mississippi

Valley below Muscatine. If the post-Nebraskan Mississippi River followed a course across Illinois by way of the Princeton Valley and down the Illinois Valley to join Trowbridge's pre-Nebraskan river at Grafton, the river would have had a descent from about 1000 feet near Galena to about 300 feet at the mouth of the Illinois, or about 3 feet per mile. Possible supporting evidence for such a history is the reported presence of Nebraskan till in the Poweshick Channel in Iowa (Trowbridge, 1959), the greater width of the Mississippi Valley below Keokuk than the Illinois Valley below Beardstown, and the location of the Nebraskan lobe.

A very different concept results if one considers the possibility that the present position of the Mississippi River across the Ozarks in southern Illinois was not determined until Nebraskan glaciation. The position of the Mississippi River near the margin of glaciation on the flank of the Ozarks is comparable to its position on the flank of the Wisconsin Highlands. Flint (1941) considered the river to have been entrenched on the Ozark Dome by uplift before glaciation. The presence near the Mississippi Valley of pre-Illinoian drift generally correlated with Kansan has long been recognized (MacClintock, 1926, 1929, 1933), and Leverett (1924) suggested that the boulders at high levels west of the valley on the slope of the Ozarks in southeastern Missouri represented Nebraskan glaciation. If drainage from northern Illinois was diverted across the Ozarks to the head of the Mississippi Embayment by Nebraskan glaciers, this, also, would have completely changed the drainage pattern and produced an adequate gradient for deep dissection.

Gradients of the bedrock floor of the major valley south from Jo Daviess County require explanation. The bedrock floor below Couler Valley and at the Bridgeport Terrace are at, or slightly above an elevation of 400 feet, whereas the bedrock floor of the buried Princeton Valley in Bureau County, Illinois, is at or below an elevation of 300 feet. Because the Sankoty Sand that fills the bottom of the Princeton Valley has been dated as Kansan on the basis of both stratigraphic relations and mineral composition (Horberg, 1950; MacClintock and Willman, 1959), and because the deposits of Couler Valley and the Bridgeport Terrace are also considered to be Kansan, a gradient of more than 100 feet occurs within a distance of less than 100 miles of valley. On the other hand, the bedrock floor of the deepest part of the Mississippi Valley at Dubuque is at an elevation of less than 300 feet (Horberg, 1950), and, therefore, it probably has a slightly reversed gradient with regard to Princeton Valley. Also, because the deposits of Couler Valley and Bridgeport Terrace are dated as Kansan, the deposits that fill the deep bedrock trench in Jo Daviess County must be younger.

The phenomena of isostatic crustal downbending under the load of glacial ice accompanied by forebulge (or upwarping) in the belt peripheral to the glacier (Frye, 1963; McGinnis, 1968) may explain these relationships. The configuration of the western Kansan glacial lobe was such that the Ancient Mississippi River by way of the Illinois Valley roughly paralleled it, and, therefore, the lines of equal depression or elevation would have been roughly parallel to the major stream valley. An eastern Kansan lobe approached the middle Illinois Valley from the east, and, therefore, may have prevented the same degree of forebulge development there as in northwestern Illinois. This may explain the relatively flat gradient of the bedrock valley in central Illinois.

The isostatic bending caused by the Illinoian glacier may explain the deep incision in Jo Daviess County. The Illinoian glacial lobes, advancing across Illinois from the northeast, completely covered the Princeton Valley, and, therefore, it was within the isostatically depressed area. In strong contrast, the Illinoian

glaciers did not reach to within 35 miles of Dubuque, and during most of Illinoian time the glacier front was at a much greater distance. Thus, the northwestern corner of Jo Daviess County was well within the area of the forebulge at the same time the Princeton Valley was depressed. During the time of maximum stand of the Illinoian glacier, drainage from the upwarped Jo Daviess County area flowed across eastern Iowa by way of the Goose Lake and Leverett Channels (Trowbridge, 1959) to the Mississippi River. Only by upwarping of Jo Daviess County could an adequate gradient for deep cutting be developed at that time.

Furthermore, although adjustments of the crust undoubtedly started with the retreat of the glaciers, they were markedly slower than glacial retreat, and therefore, for a significant time, a greatly exaggerated gradient would have existed from this area to the area immediately to the south-southeast and would account for the return of major drainage to the Princeton Valley. Such a gradient may have been as much as several hundred feet (McGinnis, 1968). Forebulge uplift in the Driftless Area may have accounted for the rapid and deep incision of the Mississippi River Valley, and the contemporaneous depression of the Princeton Valley permitted the river to flow through it without removing the Kansan outwash fill. After subsidence of the forebulge and the elevation of the depressed area, the deeply cut channel through Jo Daviess County became relatively low with a reversed bedrock gradient, and alluvial deposits filled the deep channel to its present level.

Because of the extensive dissection of the late Tertiary surface, as indicated by the unusual outwash deposits in the Driftless Area of Illinois and the probability that isostatic movements induced by the glaciers modified the gradients and depths of erosion, very little evidence remains for the reconstruction of the former drainage patterns or direction of flow in major valleys.

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GEOLOGIC SECTIONS

The following are geologic sections from which samples were collected for this study. The sample numbers, for example P-6282, are the file numbers at the Illinois State Geological Survey. The sections are arranged alphabetically by name.

DIXON CREEK EAST SECTION

In new roadcuts along U. S. Highway 20, SW¼ Sec. 35, T. 29 N., R. 2 W., Jo Daviess County, Illinois (1968).

Thickness (feet)

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria Loess

5. Loess, leached but calcareous in basal ½-foot, tan, massive; surface soil truncated (P-6283 base) 4.0

Altonian Substage
Roxana Silt

4. Silt, calcareous, chocolate brown, platy, sharp erosional contact at top (P-6282) 0.5

Illinoian Stage
Loveland Silt

3. Colluvium of silt, clay, sand, and chert pebbles, leached red to orange-red; no pebbles of quartz or igneous rocks; B-zone of Sangamon Soil (P-6281). . . 1.5

Yarmouthian Stage

2. Residual clay, leached, red-brown; contains some silt, sand, and small chert pebbles; Yarmouth Soil developed on dolomite gravel (P-6280). 1.5

Nebraskan Stage

1. Gravel, well rounded dolomite pebbles and cobbles up to 1 foot in diameter, with sand and some silt and clay; poorly sorted, not bedded, uncemented; dolomite cobbles are all solution pitted and etched but matrix is calcareous throughout; contains pebbles of chert and quartz but lacks igneous pebbles; rests on Galena Dolomite. 30.0

Total 37.5

DIXON CREEK SOUTH SECTION

In roadcut of U. S. Highway 20, NW¼ NE¼ NE¼ Sec. 2, T. 28 N., R. 2 W., Jo Daviess County, Illinois (1968).

Thickness (feet)

Pleistocene Series
Wisconsinan Stage
Altonian Substage

5. Sand, leached, well sorted, massive to indistinctly bedded, tan to tan-brown (P-6307 lower part). (In the series of cuts westward from here to the Mississippi Valley, this leached sand is overlain unconformably by calcareous sand that is the valley-margin equivalent of the Peoria Loess and contains a terrestrial snail fauna similar to that of the Peoria.); maximum thickness 15.0

Nebraskan Stage

4. Gravel, like in Dixon Creek East Section; a residuum at top consists of chert and quartz pebbles in a red-brown clay matrix; the gravel pinches out both east and west in the cut against high bedrock, but the weathered zone at top continues onto the surface of the dolomite bedrock; maximum thickness 5.0
3. Silt, sandy, clayey, red-brown, weakly calcareous to locally leached; maximum thickness 1.0
2. Silt, sandy, clayey, calcareous, gray and yellow-tan, mottled and streaked (P-6308); fills small channel cut into the dolomite bedrock; maximum thickness. 5.0

Ordovician System
Galena Dolomite

1. Dolomite, well jointed, erosional surface at top. . . . .

Total 26.0

DIXON CREEK NORTH SECTION

In new roadcut along U. S. Highway 20, SW¼ SE¼ SW¼ Sec. 35, T. 29 N., R. 2 W., Jo Daviess County, Illinois (1968).

Pleistocene Series
Wisconsinan Stage or older

5. Sand, silty, clayey, leached, tan-brown, massive, truncated surface soil in top (P-6290). 2.0

Yarmouthian Stage

4. Clay, leached, red, contains some pebbles of chert and quartz; truncated residual Yarmouth Soil on dolomite gravel (P-6289) 0.5

Nebraskan Stage

3. Gravel, like in Dixon Creek East Section (P-6288, P-6312 upper; P-6311 lower). 12.0
2. Silt, sandy, clayey, calcareous, gray and yellow-tan, mottled and streaked; pinches out on bedrock highs at east and west ends of cut; distinctly bedded with low-angle dip to east; sandier in upper

Thickness (feet)

part and clay predominates in the base at the lowest point on bedrock; local calcite cemented zone parallel to bedding in mid part; at the top, a few inches are partly leached and oxidized to brown (P-6287, P-6310, P-6309 upper part; P-6286 from cemented zone; P-6285, P-6284 lower). 9.0

Ordovician System
Galena Dolomite

1. Dolomite, well jointed, erosional surface at top; open joints filled with silty clay similar to the overlying material in contrast to residual clay filling joints in sections farther east. . . . . . . —

Total 23.5

JULIEN, IOWA, SECTION

In fresh cuts along the relocated U. S. Highway 20, center N. Line, NW¼ Sec. 32, T. 89 N., R. 2 E., Dubuque County, Iowa (1959).

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria Loess

6. Loess, leached, tan grading downward to gray; surface soil in top (samples P-515 lower; P-516 upper) 7.0
5. Loess, calcareous to weakly calcareous, gray, massive, fossil snail shells sparsely distributed in lower third (samples P-513 lower; P-514 upper). . 8.0

Altonian Substage
Roxana Silt

4. Loess, leached, dark gray, compact, massive; contains limonite tubules (sample P-512). 2.0
3. Silt, coarse, leached, yellow-tan, massive, compact (sample P-511). 1.5

Nebraskan Stage

2. Till, clayey, gray-tan, massive, compact; contains limestone cobbles throughout but matrix is calcareous only in lower part; this till appears to overlie the till below with erosional unconformity and pinches out westward in the cut; at top, a truncated soil profile is represented only by brown B_3-zone and lag gravel on the till surface (samples P-508 to P-510); maximum thickness 10.0
1. Till, sandy and cobbly, tan and gray with brown streaks; contains very few limestone boulders, and igneous boulders range from relatively fresh to rotten; contains two crenulate zones of sand and gravel and in the upper part a zone of black Mn-Fe concentration; where not overlain by bed 2, uppermost part has truncated soil and lag gravel on the till surface (samples P-506, P-507); maximum thickness 18.0

Total 46.5

LITTLE MENOMINEE EAST SECTION

In roadcut of U. S. Highway 20, SE¼ SW¼ SE¼ Sec. 31, T. 29 N., R. 1 W., Jo Daviess County, Illinois (1968).

Pleistocene Series
Wisconsinan Stage
Woodfordian Substage
Peoria Loess

7. Loess, leached, massive, tan-brown, clayey, contains surface soil in top. . . 12.0
6. Loess, calcareous, gray streaked with tan, tan in upper part (sample P-6297 lower; P-6298 upper). 3.0
5. Silt, weakly calcareous, banded tan, gray, and brown; contains limonite zone at top (P-6296) 0.5

Altonian Substage
Roxana Silt

4. Silt, leached, purplish brown; contains crenulate laminations and a well developed micro-blocky structure (P-6295). 1.0

Illinoian Stage
Loveland Silt

3. Silt, clayey with very fine sand, leached, brick-red at top to reddish brown in lower part; crumbly, friable structure at top to micro-blocky in lower part, compact; some limonite cementation at top (sample P-6293 lower; P-6294 upper) 1.5

Yarmouthian Stage and older

2. Residual clay, red, massive, leached; fills widened joints in the dolomite below to depths of more than 5 feet but pinches out on the high areas of dolomite where bed 3 rests directly on the dolomite (sample P-6292, 1 foot below top); average thickness 1.0

Ordovician System
Galena Dolomite

1. Dolomite, prominently jointed (P-6299); exposed 5.0

Total 24.0

LITTLE MENOMINEE WEST SECTION

In roadcuts of U. S. Highway 20, NE¼ NW¼ NE¼ Sec. 1, T. 28 N., R. 1 W., Jo Daviess County, Illinois (1968).

	Thickness (feet)
Pleistocene Series	
Wisconsinan Stage	
Woodfordian Substage	
Peoria Loess	
6. Loess, leached, massive, tan-brown in upper part and gray streaked with tan in lower part; contains a few limonite-filled krotovinas in lower part (P-6306)	7.0
Altonian Substage	
Roxana Silt	
5. Silt, leached, purplish brown, compact, platy structure (P-6305 top; P-6304 bottom)	1.5
Illinoian Stage	
Loveland Silt	
4. Silt, with some clay and very fine sand; contains a few small chert and quartz pebbles; leached, rusty tan, massive (truncated Sangamon Soil) (P-6303 upper; P-6302 lower)	1.5
Yarmouthian Stage or older	
3. Chert gravel, contains a few quartz pebbles, matrix of red clay and silt (P-6301)	0.5
2. Clay, red, leached, massive; residual soil on dolomite bedrock (P-6300)	1.5
Ordovician System	
Galena Dolomite	
1. Dolomite to bottom of roadcut	—
Total	12.0

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